Galaxy Clusters and Mass-Observable Scatter

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Introduction

Simple scaling relationships among the bulk properties of galaxy clusters establish a vital link between observables and halo mass and endows clusters with great potential as tools for precision cosmology. However, realizing that potential requires a better understanding of the scatter in mass-observable scaling relations. Structural variations in the intracluster media (ICM) offer a window into the dynamical variation among clusters which is the source of scatter. We report measurements of cluster dynamic state by quantifying ICM surface-brightness substructure in a sample of 121 simulated galaxy clusters, and demonstrate that this additional information reduces the scatter in the mass-temperature relationship T_X. We also discuss an alternative measure of cluster dynamical state, using the "temperature ratio" of Mathiesen & Evrard (2001) for which Cavagnolo et al. (2008) recently conducted an extensive *Chandra* archival study.

We are grateful to Stefano Borgani and Alexandro Saro for our dataset of 121 simulated clusters. These clusters were simulated with radiative cooling and supernova feedback, using the cosmological hydrodynamics TREE+SPH code Gadget-2 (Springel 2005).

Temperature

Galaxy clusters exhibit a simple scaling relationship between halo mass M and ICM X-ray temperature T_X.

$$M \propto T_X^{\alpha}$$

However, deviations from this relationship—related to cluster dynamical state—introduce scatter in mass estimates. Figure 1 shows that, in our simulation sample, clusters "hotter" than the mean appear more relaxed, while many "cooler" clusters contain merging systems of cool gas.

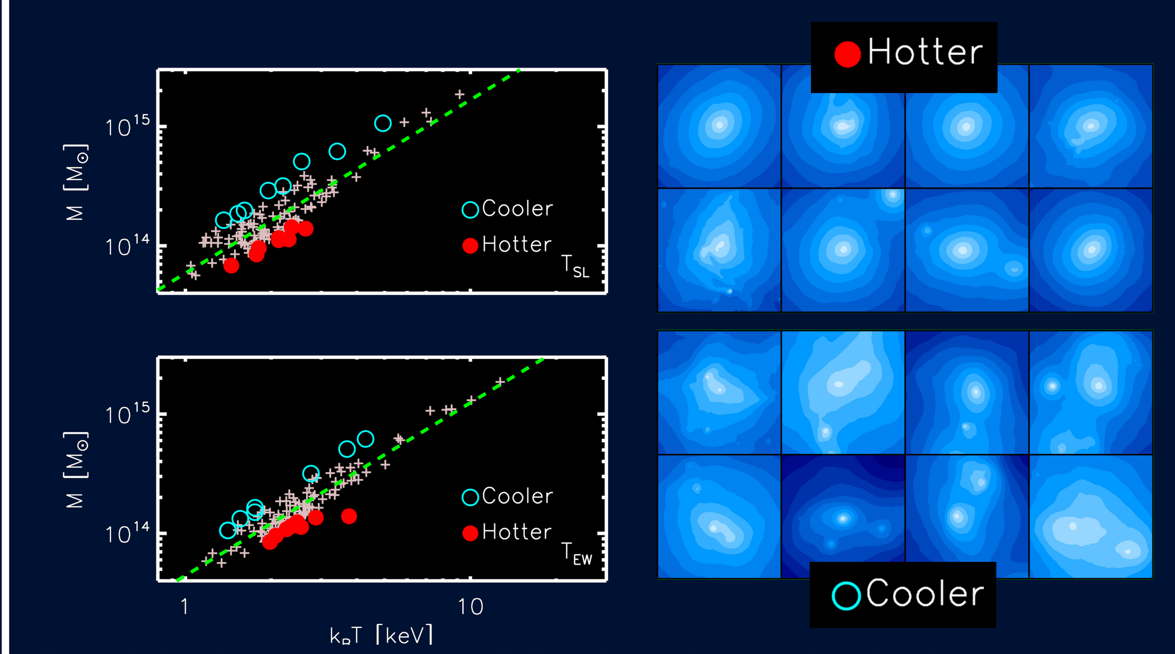

Fig.—1 (*left*) Mass-temperature (***M-T_X***) relationships for the 121 clusters in our simulation sample, for both the spectroscopic-like temperature T_{SL} (*top*) and the emission-weighted temperature T_{EW} (*bottom*). The green dashed lines show the best-fit relation, and the circles represent clusters having the greatest deviation from the mean. (*right*) Surface-brightness contour maps for the 16 clusters in the top-left panel. Notice that the "Cooler" clusters have more apparent substructure than do the "Hotter" clusters.

Substructure

Offsets from a mass-observable relationship are generally related to structural differences among clusters. We quantified this variation in a substructure parameter S with which we can compute a correction term in a new, reduced-scatter mass-observable relationship.

$$M \propto T_X^{\alpha} S^{\beta}$$

We adopt three measures of substructure from Buote & Tsai (1995) and O'Hara et al. (2004), which are illustrated in Figure 2.

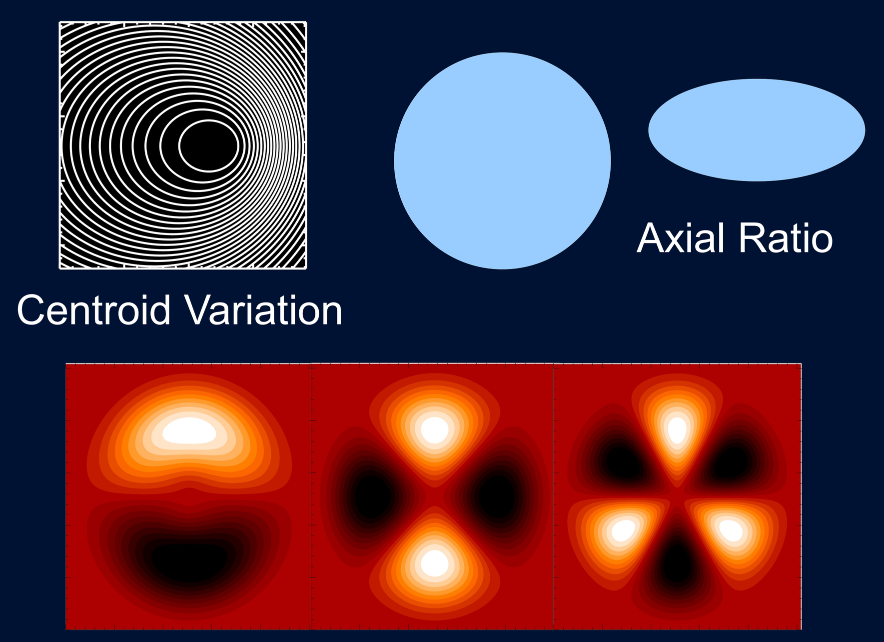

Fig. 2—Methods of quantifying surface-brightness substructure. (*top left*) Centroid Variation measures shift of isophotal contours. (*top right*) Axial Ratio is related to ellipticity. (*bottom*) Power Ratios measure the contribution from different angular moments, scaled to the zeroth moment P_0, which measures the total flux.

Figures 3 and 4 summarize our results, showing that substructure correlates with mass offset—albeit with considerable scatter—such that it yields more accurate mass estimates.

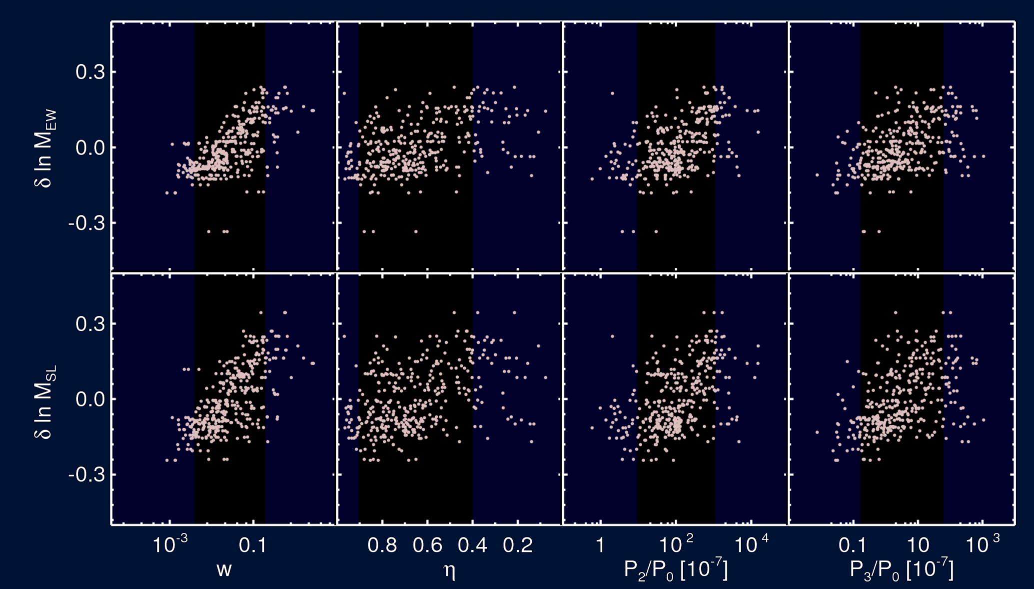

Fig. 3—Relation between mass-offset and four measures of substructure: centroid variation w, axial ratio n, and power ratios P_2/P_0 and P_3/P_0. (*top*) Masses estimated using the "spectroscopic-like" temperature T_{SL}. (*bottom*) Masses estimated using the emission-weighted temperature T_{EW}.

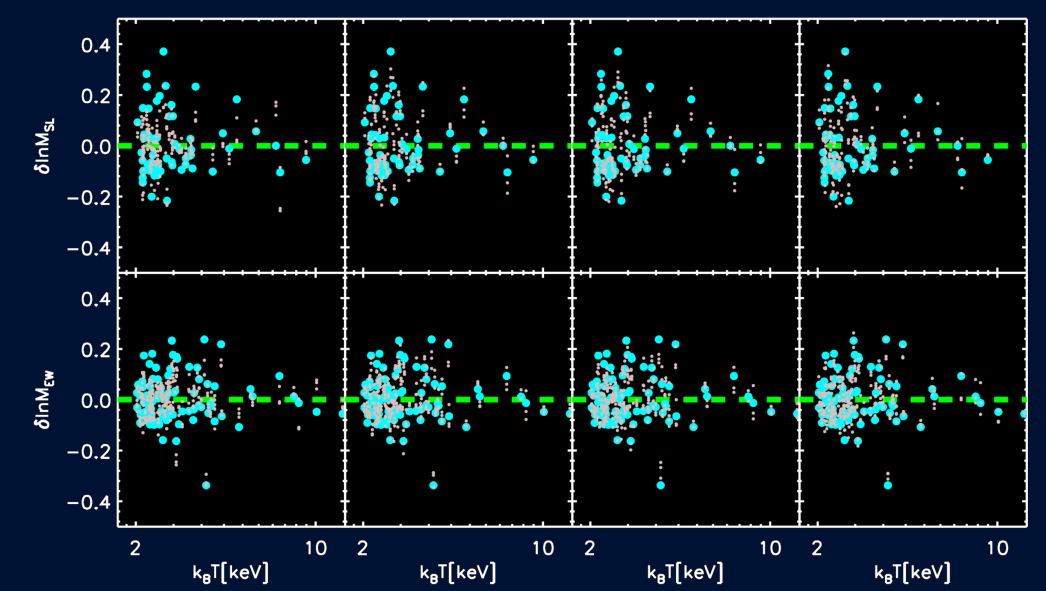

Fig. 4—Residuals for two different mass estimates, one using just the ICM X-ray temperature T_X (blue circles) and another that adds information from substructure S (pink dots). Upper panels are for masses estimated from the "spectroscopic-like" temperature T_{SL} and lower panels are for masses estimated from the emission-weighted temperature T_{EW}.

Temperature Inhomogeneity

Using hydrodynamic cluster simulations, Mathiesen and Evrard (2001) found that merger systems tend to have spectroscopically-unresolved lumps of cool gas whose soft X-ray emission suppresses spectral-fit temperatures. Scaling this to a hard-band temperature yields a statistic whose departure from unity tracks with cluster dynamical state, a conclusion which is supported by the recent *Chandra* archival study in Cavagnolo et al. (2008). As illustrated by Figure 5, among 192 well-observed clusters, they found that a ratio of hard-band to full-band temperatures $T_{HBR} > 1.1$ tended to be associated with merging systems.

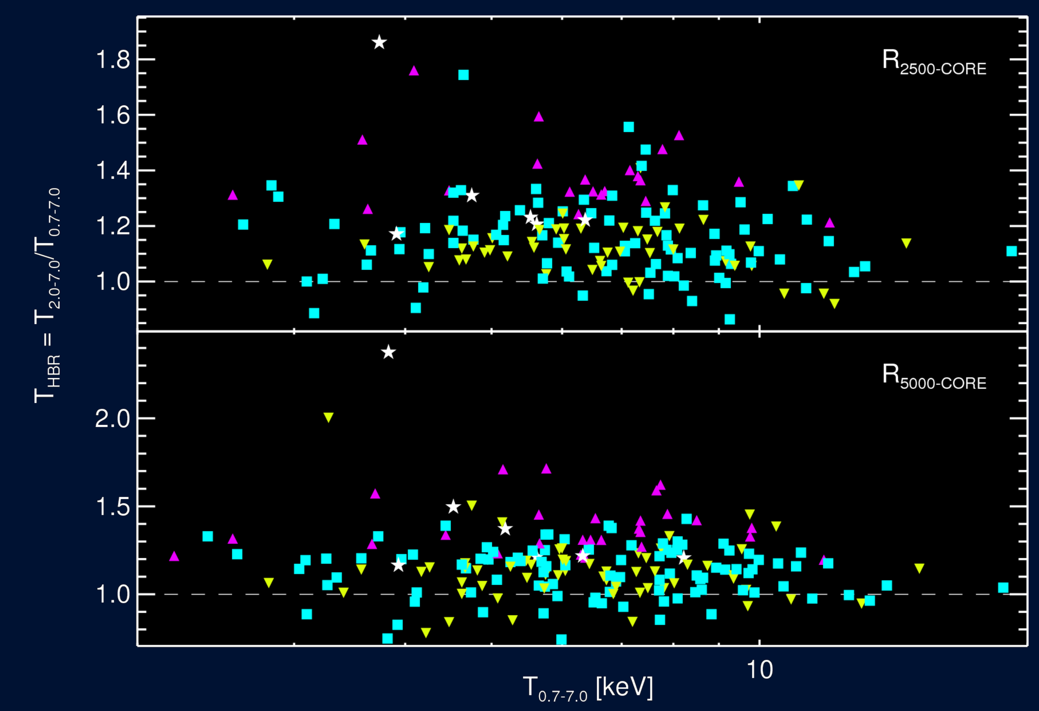

Figure 5—Temperature ratio T_{HBR} of the "hard-band" (2.0-7.0 keV) to "full-band" (0.7-7.0 keV) spectral-fit temperatures using R_{2500} and R_{5000} apertures, for 192 galaxy clusters selected from the *Chandra* Data Archive. Most of these clusters are merging systems (Cavagnolo et al. 2008).

Next Steps

- Measure T_{HBR} for 121 clusters in our simulation sample.
- Test T_{HBR} as a way to reduce mass-temperature scatter.
- Compare distributions of T_{HBR} between the Cavagnolo et al. 2008 *Chandra* sample and the simulation sample.
- Combine ICM surface-brightness substructure measurements S and temperature ratios T_{HBR} to study the effects of scatter and evolution of scatter on Dark Energy parameters determined from cluster surveys.

References

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